# A Thorough Evaluation of the Performance Capability and Uncertainties of the Umkehr method

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## Abstract

The framework of the new Umkehr ozone profile retrieval algorithm (Mateer and DeLuisi, 1992) sufficiently incorporates all important and fundamental physics involved in the inverse model; although, not all of the physics may be implemented fully. Our ongoing effort builds upon this framework by updating the a priori information on ozone profile, and atmospheric temperature and pressure. Improvement to the forward model radiative transfer coding was also investigated. The 1998 Umkehr ozone profile retrieval algorithm work is leading to improved accuracy of the profile retrievals and improved calculations of the stratospheric aerosol errors, so that ozone trends can be determined with improved reliability.

* A study of the first-guess (FG) ozone profile errors showed that application of the updated first-guess ozone profile information improved the retrieved Umkehr ozone profiles in layers 1-6 when compared to ozone sonde data for Boulder, $40^0$ N; however, further upgrading is needed to account for the deviations from the simple cosine fit that is currently used to include the annual cycle in the FG algorithm.

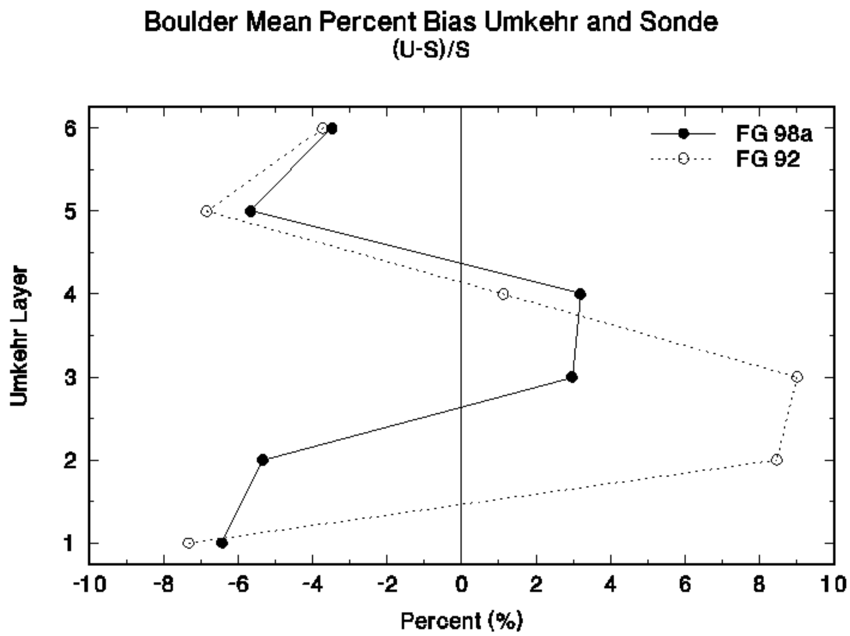


Fig.1 Comparison of retrieved Umkehr ozone profile with ozonesonde observations in Boulder, CO, showing improved agreement with the updated 98 FG a priori information.

* The capability of the 1992 Umkehr algorithm to retrieve subtle changes in the ozone profile, such as caused by a trend, was studied. Results showed that Umkehr algorithm is capable of reconstructing the given trend above 20 km. The capability of the New Umkehr ozone profile retrieval algorithm to detect a trend is questionable in the lower layers. One problem is the first-guess ozone profile effect on the ozone retrieval in the lowest layers. Nevertheless, the total ozone change in the lower layer is conserved.

It was determined that a priori statistics influences the Umkehr ozone profile trend analysis in the lower atmosphere. The cause is the dependence of the ozone retrieval on the first guess ozone profile. Since the a priori profile in the lower atmosphere (layers 1-5) is dependent on the total ozone, total ozone trends create a trend in the lower atmosphere first-guess profiles; thus biasing the Umkehr retrieved ozone trend to the a priori statistics. There is very little ozone profile information in the lower atmosphere contained in the Umkehr measurement itself. However, since the Umkehr profile in the lower atmosphere represents the column total ozone up to layer 4, the the a priori first-guess determines the most probable profile distribution, that a change in total ozone would manifest itself.

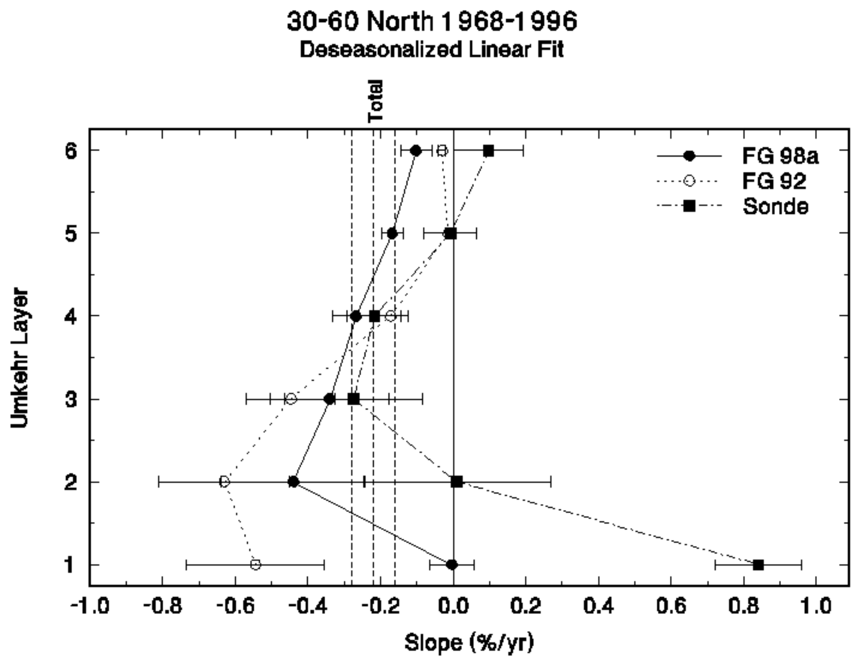


Fig. 2. Comparison of ozone profile trends in Umkehr layers derived from ozonesonde data (black squares), first-guess ozone profile in the 1992 Umkehr retrieval algorithm (dots), and updated first-guess (open circles). Results stress FG influence of the Umkehr retrieval and its possible interference with the trend analysis. Vertical dashed lines show the total ozone trend estimate. FG98a is the updated first-guess ozone profile algorithm, and FG92 is the first-guess algorithm used in Mateer and DeLuisi (1992).

* A new method for ozone profile trend analysis has been developed. The method determines trend in Umkehr observations (normalized to $60^0$ SZA measurements) and apply derived difference to retrieve trend in ozone profile. The advantage of the method is the elimination of the a priori statistics influence. The result of this study indicates a strong robustness of the Umkehr trend information in layers 4-9.

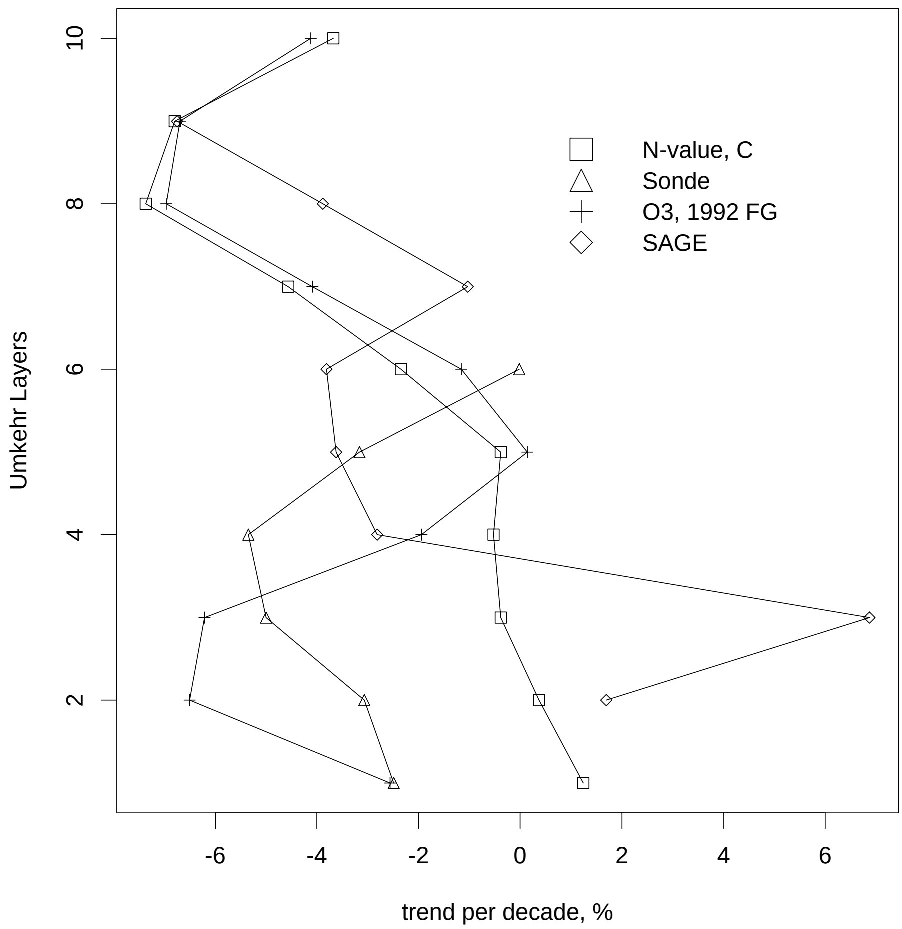


Fig. 3. Comparison of Ozone trends in Umkehr layers derived from Boulder Umkehr measurements: using trend information in Umkehr radiance observations (open squares); ozone-sonde data (open triangles); Umkehr retrieved ozone profile using the 1992 algorithm with first-guess information (pluses); SAGE II data (open diamonds). Note that the N-value inversion shows virtually no trend, but the $O_3$ (+) inversion distributes the total ozone in a profile most compatible with the a priori information.

* Explanation of the biases in SBUV satellite and Umkehr retrieved ozone profile comparisons was found to be due to the first guess choice used in the algorithms. The bias between Umkehr and SBUV retrieved ozone was largely reduced (less than 3 %) by using SBUV first guess profiles in place of what is used in the Umkehr retrieval algorithm. The application of different covariance matrices did not have a significant impact on the retrieval (less than 2 %). Application of the exact multiple scattering corrections showed only small effect on the accuracy of the retrieval. However, the effect could become notable when temperature/pressure profile is chosen with respect to seasonal/latitude variation of test ozone profiles (SAGE observations, for example).

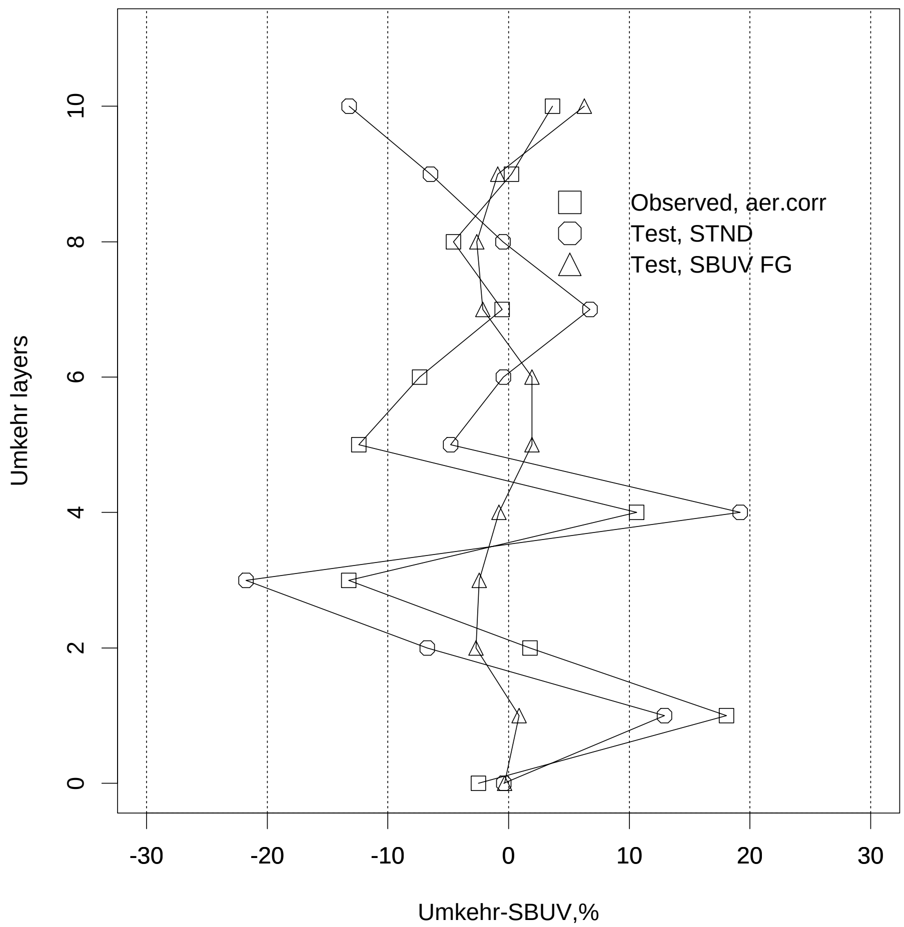


Fig. 4 Profile bias between Umkehr and SBUV retrieved ozone profiles. The symbols are as following: 1992 Umkehr retrieval (open circles); Umkehr retrieval with SBUV first guess applied (open triangles); one-on-one SBUV/Umkehr data in Umkehr layers for the average of 5 northern mid-latitude stations (open squares). Umkehr data were corrected to remove aerosol error.

* Customizing the Umkehr algorithm for individual stations becomes possible with complete forward vector model that enables the algorithm to calculate accurate multiple-scattering corrections for retrieved ozone profile, including application of the NMC temperature climatology for ozone absorption coefficient and multiple scattering corrections, application of ozone climatology for the first-guess ozone profile determination (application of the forward model for the Brewer instrument is also possible and could be done in collaboration with the Canadian Atmospheric Environment Service).

* The accuracy of radiative transfer computer codes used in the new and old retrieval algorithms and the calculation of aerosol error has been assessed. A number of the radiative transfer code had been used for these study. Among them there are Dave's (1978) scalar code (SPD), Herman's et al. (1995) complete spherical vector code (HV), Herman's et al. (1994) fully spherical scalar code (HS) (private communication), Dave-Mateer's (Dave, 1964) pseudo-spherical vector code (DM), Dave's (1968) pseudo-spherical atmosphere with polarization taken into account (VPD) code, Monte Carlo code (MC) (Lenoble, 1985), and two iterative methods of Successive Orders of Scattering (pseudo-spherical without polarization included (SOSL) (Lenoble, 1985) and fully spherical without polarization included (SOSB) (Belikov et al., 1993)). The calculated ozone profile errors due to the stratospheric aerosol effect are sensitive to the selected RT code. We determined that ozone errors can differ by 0-45 % when the polarization effect is not taken into account and for a large aerosol optical depth of 0.11.

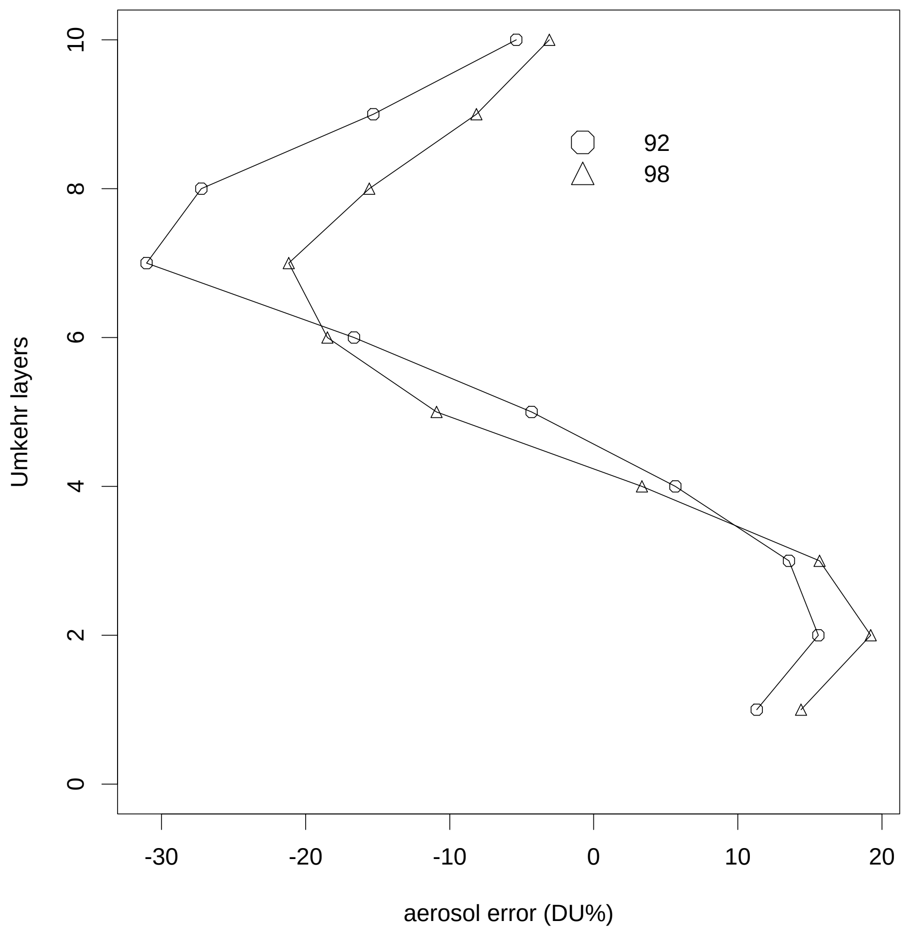


Fig. 5 Comparison of stratospheric aerosol errors calculated with the use of Dave’s scalar code (92) and his vector code (98). Stratospheric aerosol optical thickness is 0.11, total ozone is 350 DU. The reference is Petropavlovskikh et al. (1996).

* The stratospheric aerosol error correction estimation procedure was further developed. It involves an archive of the stratospheric aerosol profile time-series going back to 1960s, ozone profile climatology (SAGE II, Ozone-sonde), application of the Dave radiative transfer vector code, simulation of the Umkehr observations for clear and elevated stratospheric aerosol conditions, and application of the Umkehr ozone profile retrieval algorithm. An estimation procedure to calculate aerosol errors for Brewer instruments is being considered for development in collaboration with the Canadian Atmospheric Environment Service.

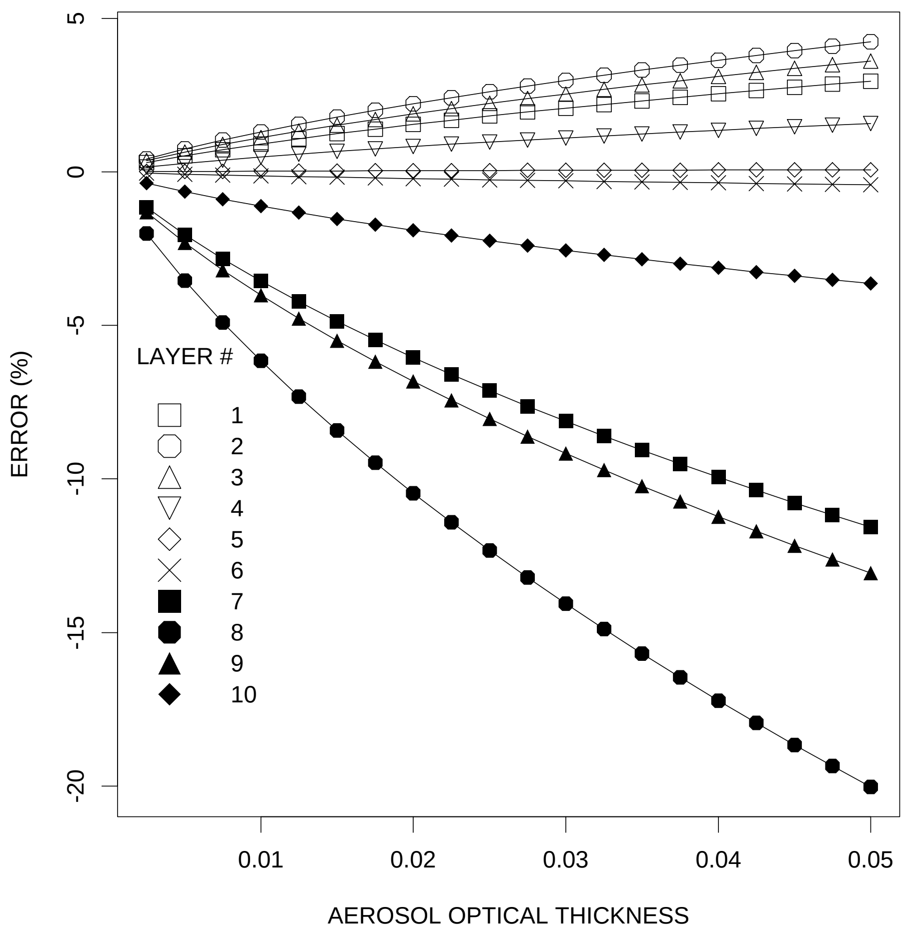


Fig. 6. . Plots of 1992 Umkehr stratospheric aerosol errors as a function of aerosol optical thickness and Umkehr layers. The reference is DeLuisi et al. (1996).

* An investigation into the nature of the vertical profile of the aerosol error to the Umkehr ozone profile as affected by aerosols at different altitudes was conducted, using a linear multivariate regression analysis. It was found that the error contribution to a given layer from aerosols in other layers (including the given layer) can be either positive or negative;  the magnitudes of the contributions (absolute error) vary according to the amount of aerosol in a layer and the altitude location of the layer; the contribution of the aerosol in the layer with the maximum load (usually layer 4) produces a strong effect in most layers. Ozone profile error caused by tropospheric aerosols had been also studied.

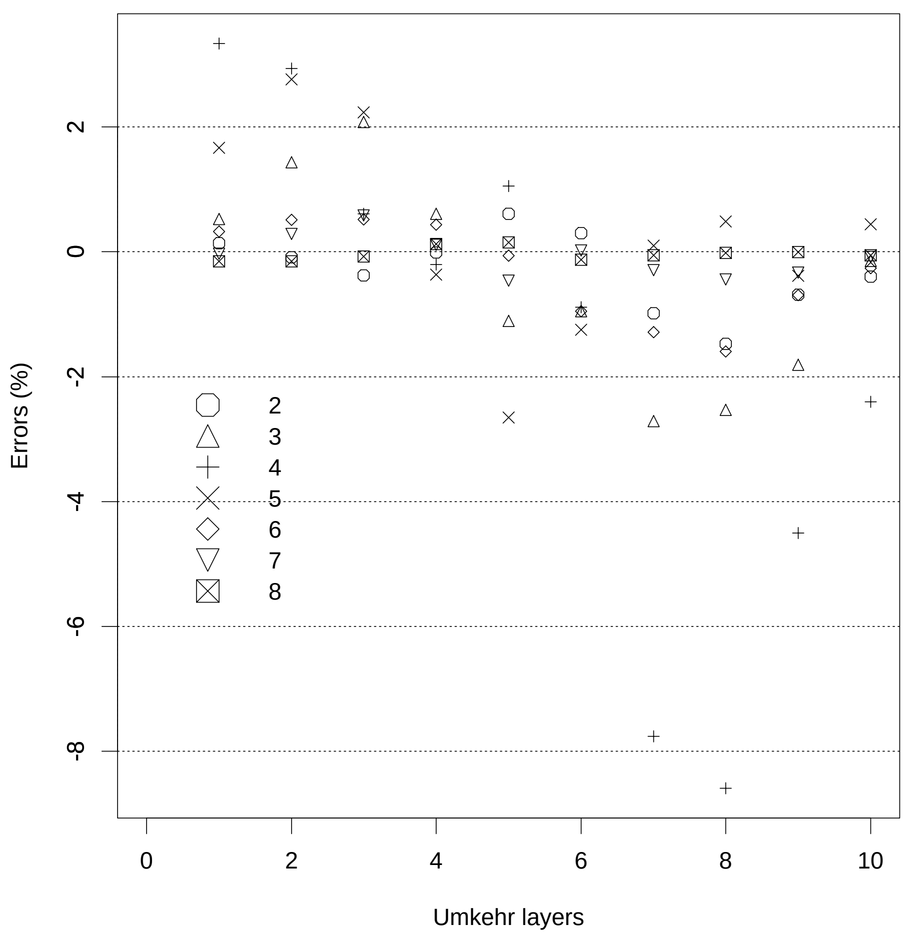


Fig. 7 Contribution to errors in layers 1 - 10 from aerosol in layers 2 - 8. Error calculations are performed using 1992 Umkehr algorithm for a large population of aerosol profiles and a total ozone of 350 DU. The abscissa presents Umkehr layers, and the ordinate represents absolute errors in layers 1 - 10. The legend shows symbols corresponding to the location of the aerosol (Umkehr layers 2 - 8).

* Collection and application of stratospheric aerosol information has continued. A total of 79 stratospheric aerosol size-distributions observed during elevated conditions in 1982 and 1992-93 were used to produce a functional relationship between calculated Mie extinction/Rayleigh extinction and Mie backscattering/Rayleigh backscattering at lidar wavelengths 694 and 532 nm. From this relationship the extinction to backscatter ratio is calculated to predict from lidar measurements aerosol extinction at SAGE wavelengths. Rayleigh extinction and backscatter were calculated from air density at the altitude of the aerosol size-distribution measurement. This work is in the exploratory stage. It is intended to characterize stratospheric aerosol properties in the context of a quasi-universal and bounded process for every volcanic episode.

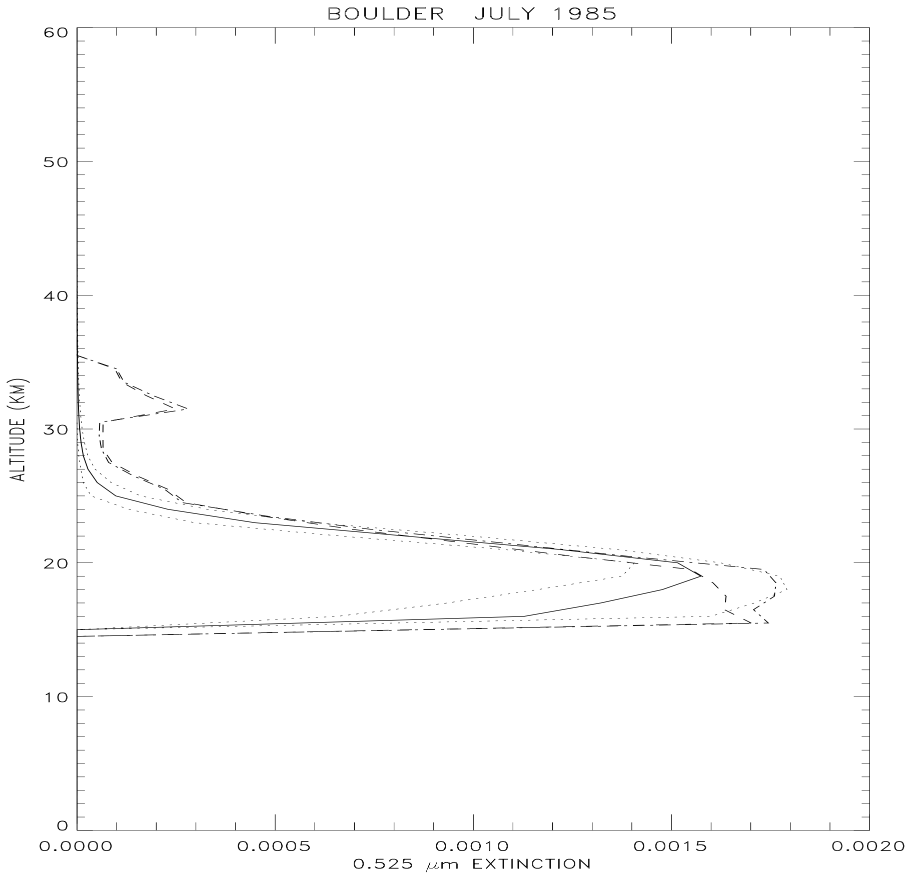


Fig. 8. Comparison of 525 nm aerosol extinction profiles (monthly averaged, July, 1985): SAGE II measurements (solid line) along with ±1σ range of uncertainties (dotted line); extinction profile derived from 694 nm lidar backscatter profile measured in Boulder (CO, USA) using non-linear functional fit (dashed line) and a log-functional fit (dash-dotted line).

**Papers published and in press:**


1. Congeduti, F., J. DeLuisi, T. DeFoor, and L. Thomason, Optical extinction properties of volcanic stratospheric aerosol derived from ground-based lidar and sun-photometer measurements, (in review, JGR, 1998).

2. DeLuisi, J.J., I.V. Petropavlovskikh, C.L. Mateer, An evaluation of the uncertainties in estimating stratospheric aerosol errors to retrieved Umkehr ozone profiles, Proceedings from the XVIII Quadrennial Ozone Symposium in L'Aquila, Italy, 1996

3. Mateer, C. L., H. U. Dütsch, J. Staehelin, and J. J. DeLuisi, Influence of a priori profiles on trend calculations from Umkehr data, J. Geophys. Res., 101, pp. 16,779-16,787, 1996.

4. Petropavlovskikh, I.V., B. Herman, R. Lougman, P. K. Bhartia, C. L. Mateer, J. Lenoble, Y. Belikov, A comparison of radiance calculations by spherical atmosphere radiation transfer codes for modeling the Umkehr effect, Proceedings from the XVIII Quadrennial Ozone Symposium in L'Aquila, Italy, 1996

5. Petropavlovskikh, I.V., L. Flynn, J. DeLuisi, P.K. Bhartia, A critical look at the capabilities of the Umkehr and SBUV for ozone information below 20 km, Proceedings from the XVIII Quadrennial Ozone Symposium in L'Aquila, Italy, 1996

6. Miller, A.J., L.E. Flynn, S.M. Hollandsworth, J.J. DeLuisi, I.V. Petropavlovskikh, G.C. Tiao, G.C. Reinsel, D.J. Wuebbles, J. Kerr, R.M. Nagatani, L. Bishop, and C.H. Jackman, Information content of Umkehr and solar backscattered ultraviolet (SBUV) 2 satellite data for ozone trends and solar responses in the stratosphere, J. Geophys. Res., 102, D15, pg. 19257-19263, 1997.

7. Wenny, B.N., J. S. Schafer, J. J. DeLuisi, V. K. Saxena, W. F. Barnard, I. V. Petropavlovskikh, and A. J. Vergamini, Field experiment determination of aerosol radiative properties and effects in the Ultraviolet-B region, (in review, JGR, 1998).

8. Yu, S., V. K. Saxena, B. N. Wenny, J. J. DeLuisi, G. K. Yue and I.V. Petropavlovskikh, A study of the diffuse to direct solar irradiance ratio and aerosol optical depth in the southeastern US, J. Geophys. Res., (in review, JGR, 1998)